A STUDY IN THE FORECASTING OF WINTER PRECIPITATION FROM THE 500-mb LEVEL

John H. Powell

A STUDY INTO THE FORECASTING OF WINTER PRECIPITATION FROM THE 500-MB LEVEL

52

* * * *

John H. Powell

A STUDY INTO THE FORECASTING OF WINTER PRECIPITATION FROM THE 500-MB LEVEL

by

John H. Powell

Lieutenant, Junior Grade, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
AEROLOGY

United States Naval Postgraduate School
Monterey, California

1 9 5 7

A STUDY INTO THE FORECASTING

OF WINTER PRECIPITATION FROM

THE 500-MB LEVEL

by

John H. Powell

This work is accepted as fulfilling

the thesis requirements for the degree of

MASTER OF SCIENCE

IN

AEROLOGY

from the

United States Naval Postgraduate School

ABSTRACT

The relatively greater accuracy of prognostic 500-mb charts as compared to prognostic surface charts has led to various studies attempting to forecast surface parameters from the 500-mb level. Most of these studies have been localized studies, whereas the purpose of this study was to determine the feasibility of developing a general method for forecasting winter precipitation from parameters observed or measured at the 500-mb level.

The first approach to the problem was a statistical study of the percentages of the stations reporting precipitation in four zones of the short wave in each of four similar zones of the long wave. The four zones in each wave pattern were separated by the trough, ridge, and the inflection points of the wave. The percentages for the 16 zones defined above were plotted versus the contour gradient across the zones, the temperature gradient across the zones, and the steepness of the long-wave pattern. The scatter of these diagrams indicated that there was little or no correlation between these parameters and the percentages of precipitation in the zones.

In the second phase of this study, four graphical techniques were used: the direction of the wind, 24-hour height change patterns, the deviation of the height from the normal, and the advection of geostrophic relative vorticity. The results of these methods could be used to varying degrees of accuracy to forecast precipitation. Further study may improve the accuracy of these methods. The advection of geostrophic relative vorticity technique is the most promising one.

The writer wishes to express his appreciation for the assistance

and encouragement given him by Professor George J. Haltiner, Professor A. Boyd Mewborn, and Assistant Professor Robert J. Renard, of the U. S. Naval Postgraduate School, in this investigation.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1. Introduction

Prognostic maps of the 500-mb level obtained by objective, subjective and numerical means are widely used for forecasting upper winds, for steering of surface lows, and for other meteorological problems. There have also been many investigations into the possibilities of forecasting surface weather from a prognostic 500-mb map. Most of these investigations have been made for single stations or several stations that are considered to be representative of certain areas of the United States.

This investigation was conducted to ascertain the feasibility of developing general methods of forecasting surface parameters from the 500-mb charts, current or prognostic. No parameters were used in this study which are not available from or can not be derived from the 500-mb maps issued by the Numerical Weather Prediction Unit of the United States Weather Bureau in Suitland, Maryland.

Due to the limited time available, the only parameter investigated was winter precipitation. Unless otherwise noted, the weather maps used in the various methods attempted for forecasting precipitation were the daily series of the Synoptic Weather Maps for the Northern Hemisphere published by the United States Weather Bureau. Maps from 1950 through 1956 only were used because of the tendency to smooth the contours in maps prior to then. The months of January, February, the first half of March, and the last half of December were considered winter months by the author. Since it was not the purpose of this study to determine the accuracy of the 500-mb prognostic charts, only actual analyses were used in the various techniques. The examples taken from these maps for the various methods were taken at intervals

of three or four days. This was done to prevent any system being included twice in the sample used for any one method.

In all of the techniques used in both approaches to forecasting precipitation from the 500-mb map, the problem was initially divided into two areas of the United States, east and west of 100 degrees west longitude. Where the data indicated a difference in the results of these two areas, the methods were studied and presented separately; otherwise the data were combined.

The first approach for forecasting precipitation consisted of a tabulation of the percentage of stations reporting precipitation in four zones of the short wave for each of four similarly defined zones of the long wave. These percentages were then plotted on scatter diagrams with each of the following parameters: the contour gradient across the short wave, the temperature gradient across the short wave, and the index cycle of the long-wave pattern. The purpose here was to determine if there was any correlation between any of these parameters and the precipitation in the short wave as it moved through the long-wave pattern.

The second approach to the problem of forecasting precipitation from the 500-mb map involved the use of graphical techniques. The first method attempted to correlate the precipitation within an area with the direction of the 500-mb wind over that area. The second method was to determine if the 500-mb height change patterns could be used to forecast precipitation. The third method investigated the possibilities of forecasting precipitation by associating it with the deviation of the prognostic map from the normal 500-mb map for that month. The last method attempted to determine if advection of positive relative vorticity at 500 mbs could be used to forecast precipitation.

In both of the approaches of this study the percentage of stations reporting precipitation at map time was used to indicate the percent of precipitation in an area being considered.

2. Statistical Wave Study

This study was made to determine what areas in the short-wave patterns at 500 mbs had the maximum percentages of stations reporting precipitation associated with them and to determine if the percentages in the various areas changed as the short wave moved through the long-wave pattern, or if they changed with other parameters. The short-wave pattern was divided into four zones, as shown by Figure 1, page 20. These zones were chosen because of the relative ease and accuracy with which these boundary lines could be determined. These boundary lines were the ridge line, trough line, and the associated inflection points. The long-wave pattern was divided into four zones in the same manner as was the short-wave pattern.

Twelve months of examples were taken from the years 1950, 1952, 1953, 1955 and 1956. The short waves used were ones with a wave length of greater than twelve degrees of latitude. The percentage of the stations in each short-wave zone reporting precipitation was determined for the short wave in each of the four long-wave zones. The position of the short wave in the long-wave pattern was determined by comparison to a mean map for each day of the study. The mean was constructed by averaging the map previous to and the map following the observation day. This type of mean appeared to give satisfactory results and could be prepared in appreciably less time than the ordinary space mean.

The 75 examples taken for this study were divided among the long-wave zones as follows: 29 in zone one, 16 in zone two, 9 in zone three, and 21 in zone four. A sample size of at least 20 examples in each of the long-wave zones had been desired, but due to the tendency of the long-wave troughs to remain off the east and west coasts of North America,

examples in zones two and three were not as numerous as were the ones for zones one and four. The cases in zones two and three were further limited because the examples were taken at intervals of three or four days. This was done to prevent any one short wave being used two or more times as separate examples.

Means and standard deviations of the percentage of stations reporting precipitation were computed for the short-wave zones in the four long-wave zones. These values are listed in Table 1 and Table 2, page 20 . Frequency distribution graphs for the four short-wave zones, when the short wave was in zone one of the long wave, are shown in Figures 2 through 5, pages 21 through 22 .

The highest mean for zone one of the short wave occurred when the short wave was in zone two of the long-wave pattern and the lowest value occurred when the short wave was in zone three of the long-wave pattern. The standard deviations for this zone varied in the long-wave zones as indicated in Table 2.

The highest mean for zone two of the short wave occurred when the short wave was in zone three of the long-wave pattern and the lowest mean occurred when the short wave was in zone two of the long-wave pattern. This was opposite to the means in zone one and may show a shift in the precipitation area as the short wave moves through the long-wave pattern. The standard deviations for zone two were nearly the same for the short wave in all four of the long-wave zones.

The means for zone three of the short wave were less than the means of zones one and two. The highest mean occurred with the short wave in zone one of the long wave. The standard deviations for zone three

were not as large as the ones for zones one and two, but the standard deviations for zone three varied more.

The means for zone four were the lowest of all with a slight increase as the short wave moved through the long-wave pattern from zone four to zone one. The standard deviations for zone four were also the smallest of the four short-wave zones.

The results of the study of the short-wave pattern indicated that the majority of the precipitation occurred ahead of the trough, as was expected. The means for the short-wave zones one and two were smaller than desired. The large standard deviations showed that there was a wide variance in the individual cases. Because of this, additional parameters were selected to determine if the variance was associated with any of these parameters.

The first parameter selected was the contour gradient across each of the short-wave zones. This parameter was selected because it gave an indication of the geostrophic wind in the zone. In cases where the spacings of the contours varied laterally, the zone was divided into two areas where the spacings were fairly constant. The author considered this parameter to give an indication as to whether or not a geostrophic jet stream was in the zone being considered. Riehl [1] suggested that there should be high correlation between the position of the jet axis and precipitation areas. For each example the contour gradient was plotted versus the percentage precipitation for the short-wave zones one and two in the four long-wave zones. These two zones were used because of the relatively high percentage of precipitation found in these zones as compared to the other two zones. Example scatter diagrams for zones one and two of the long wave are shown in Figures 6 and 7, page 23.

The random scatter of the above mentioned diagrams indicates that there is no apparent correlation between the percentage of precipitation in a zone and the contour gradient across the zone. This could be due to the fact that the geostrophic wind may not be a good approximation to the true wind and hence may not indicate the true jet axis, or it could be due to the certain amount of averaging that was necessary to represent the contour gradient in a zone by a single number, thus possibly destroying the jet axis through the zone, if one had been there.

The second parameter considered in this study was the isotherm gradient across each zone. This parameter was selected because the packing of isotherms at the 500-mb level should give an indication of the intensity of the surface fronts associated with the short wave. If the spacing of the isotherms across a certain zone varied, the zone was divided into two zones of approximately equal gradient as was done for the contour gradient method. The scatter diagrams of the percentage of precipitation reported versus the isotherm gradient across the zone for short-wave zones one and two in the long-wave zone one are shown in Figures 8 and 9, page 24 . The scatter diagrams for these cases shows that there is no apparent correlation between these two parameters.

The third parameter used in this study was the relative steepness of the long-wave pattern with which the individual short waves were associated. This was used as a parameter for indicating the phase of the index cycle for each example, with a large steepness factor being associated with meridional type flow and a small steepness factor being associated with zonal type flow. The steepness factor was

determined by dividing the latitudinal difference between the trough and ridge of the lowest valued contour of the long-wave pattern by the distance in degrees latitude between the trough and ridge. This is essentially twice the amplitude divided by one-half of the wave length. These two distances are shown schematically in Figure 10, page 25 . Examples for this method were taken from all four long-wave zones because there seemed to be little difference in the scatter when precipitation was plotted versus the steepness of the long wave. These scatter diagrams for zones one and two of the short wave are shown in Figures 11 and 12, page 26 . This parameter should show an increase in precipitation with an increase in the steepness factor due to the greater intensity of frontal system weather for meridional type flow than for zonal type flow. The scatter diagrams show that this assumption was not true and that there seems to be no correlation between the percentage of precipitation in zones one and two of the short wave and the wave amplitude.

Due to poor results achieved by this method, no additional parameters were used in this study and combinations of the parameters that were tested were not attempted. It is possible that a different division of the short and long-wave patterns may achieve better results, but it is the opinion of the author that this method is of little use. This statement was made because of the number of precipitation areas noted in this study that were not associated with a short wave. These areas occurred in zones of high winds, areas of extremely loose gradients, and in other areas. As a result of these observations, an entirely different approach to the problem was attempted in the second phase of this study.

3. Graphical Methods

a. Wind Direction at the 500-mb Level. In an investigation conducted by the Pennsylvania State University for the U. S. Air Force, Miller [2] found that southerly flow was the best 500-mb indication of precipitation at Minneapolis, Minnesota. Due to his results and the association of precipitation with southwesterly flow for the west coast of the United States, an investigation was conducted into the possibility of forecasting precipitation or the lack of precipitation in any area by the direction of the 500-mb wind over this area. The wind areas used in this study were limited to areas larger than a square six degrees of latitude on a side. The total number of cases taken was 230. These cases were divided by wind direction and geographical location as shown in Tables 3 and 4, page 27 . The means and standard deviations of the percentage of precipitation for these categories are also shown in these tables. For the eastern United States, southerly flow was associated with the highest mean. The mean of 72 percent for southerly flow could be used as a forecast of precipitation and should contain 52 to 92 percent precipitation in this area 68 percent of the time. The remainder of the wind directions can be used to forecast a 68 percent precipitation range as shown by the means and standard deviations in these tables. The eastern categories are listed in Table 3, page 27 , by decreasing value of the means. The means for the various wind directions in the western area were lower than the means for the same directions in the eastern area and are listed in decreasing order in Table 4, page 27 .

Wind directions with an easterly component were not considered in this investigation due to the difficulty of obtaining examples of the

size used in this study.

b. 24-Hour Height-Change Patterns at the 500-mb Level. Fleagle [3] showed in his study of the vertical cross section through a surface low and the trough associated with it that upper level divergence overlies surface convergence. In the surface convergence zone upward vertical motions prevail and in these zones precipitation areas are found. These zones will not include all types of precipitation, such as precipitation due to thermodynamic instability, to the lake effects, or to other low level local processes.

Fleagle also showed that upper level convergence areas overlie surface divergence areas. In these areas downward vertical motions prevail. These areas should show an absence of precipitation, except for local low-level precipitation processes which may produce precipitation in these areas.

500-mb height-fall and rise centers outline areas where, in the past, upper-level divergence and convergence have predominated above the 500-mb level. Consequently a study was made to see if there was any correlation between the 24-hour height change centers and the occurrence, or absence of precipitation.

Height-fall and rise centers were defined for this study as areas in which the 500-mb height had fallen or risen 200 feet or more in 24 hours. The height-fall centers were also reduced to the areas in which the 500-mb flow was from larger to smaller fall values. In most cases, this was the leading half of the fall pattern. This was done because this area enclosed the most recent falls and should be more closely associated with the prognostic map. No similar restriction was imposed on the height-rise centers and results proved this to

be acceptable.

The percentage of the stations in fall or rise patterns reporting precipitation was determined for 50 fall and 50 rise centers. These cases were taken from six randomly selected winter months as follows: January 1950, 1953, and 1956; February 1950 and 1952; and December and March of 1952. In each case, the percentage of precipitation was plotted versus the largest height change in each height-change area. This was done for 200-foot increments only, so as to prevent errors in the estimation of the central value. If the innermost closed line was a 400-foot change, the example was classed as a 400-foot change area. If there were two adjacent tangent points on the superimposed 500-mb maps, the area was classed with this value. When more than one-third of the area was over the ocean or when the 200-foot change line was not closed, the area was not used in this study.

The 50 height-fall cases were divided as follows: 14 in the 200-foot change class, 16 in the 400-foot change class, 15 in the 600-foot change class and 5 in the 800-foot change class. The means and standard deviations for these classes are listed in Table 5, page 28 . The values listed in this table could be used to forecast precipitation using the means and standard deviations to compute 68 percent ranges. The 800-foot fall class may not verify well, because of the small number of cases in this class. The scatter diagram for these classes is shown in Figure 13, page 28.

This method of forecasting precipitation should prove to be more useful if the occurrence of precipitation, for stations in a height-fall area, was determined over an interval of six hours spanning

the prognostic map time. This was not done in this study due to the lack of this information.

In the investigation of 24-hour height-rise centers with the occurrence of precipitation, the 50 examples were divided as follows: 15 in the 200-foot change class, 19 in the 400-foot change class, and 16 in the 600-foot change class. The means and standard deviations for these classes are listed in Table 6, page 29 . The low means and the high frequency of occurrence of the modal value of zero, as shown in Figure 14, page 29 , for these classes illustrate that there is little or no precipitation in the height-rise centers. This method could be used to forecast the nonoccurrence of precipitation in the height-rise centers.

c. Deviation of the 500-mb Map from the Normal 500-mb Map for the Month.

In a study conducted by Martin and Hawkins [4], the deviation for the month of an individual monthly mean map from the normal map at 700 mbs was correlated with the total precipitation for that month. The United States was divided into several areas with wet and dry anomalies determined for each area. A positive anomaly was normally associated with clear skies and a negative anomaly with cloudiness and precipitation. This technique was developed to use as a forecast tool in connection with the monthly forecasts issued by the Extended Forecast Section of the Weather Bureau.

Due to the ease with which the deviations of a daily chart from a normal monthly chart could be constructed, a study was made to ascertain the possibilities of forecasting precipitation using this technique. The normal 500-mb charts published by the Weather Bureau [5] were used in this study. The normal charts for the months of January, February,

March, and December were traced on clear acetate to facilitate the graphical subtraction of the daily charts from them.

Examples were taken from January, February, March, and December of 1952, January and February of 1953, December 1955, and January, February, and March of 1956. There were 163 examples of which 83 were negative deviations and 80 were positive deviations. Both of the two major classes were subdivided as to whether or not a short wave was in the anomalous area. This further subdivision was made due to the difference in percentages of precipitation noted for the two types.

The 83 negative deviation examples were divided into 46 cases in which a short wave was present in the area and 37 cases where there was no short wave present. Each of the examples in the two cases were separated into classes determined by the magnitude of the largest deviation in each example. These classes were separated in the same manner as were the height-change classes. The number of occurrences, the means, and the standard deviations for each class are tabulated in Table 7, page 30 , for the eight classes. There is a definite increase in the percentage of precipitation when a short wave is in the area as opposed to when one is not present. The comparatively high means in the former type could be used to forecast precipitation to a certain degree. The large standard deviations in the first two classes of this type limit the accuracy in those classes, and the number of the examples in the 800-foot deviation class is not large enough to give conclusive results. The infrequent occurrence of the 800-foot deviation class also limits its use. When compared to the other type, the classes with no short waves present do not have as high means.

The percentages of precipitation forecast for them will have lower ranges as shown by Table 7, page 30. The scatter diagrams for both types are shown in Figures 15 and 16, page 31.

The 80 positive deviation areas were subdivided into 31 examples with a short wave in the area and 49 examples with no short waves. The two types were separated into classes in the same manner as the negative deviation classes. The number of observations, means, and standard deviations for the classes of both types are listed in Table 8, page 30.

The classes with no short waves in them have very low means and small standard deviations. The classes of this type should have a probability of .68 of having 12 or less percent precipitation in the areas they enclose. The classes with a short wave present have means nearly equal to the means for the negative deviation areas with no short wave present and should be forecast to contain these larger percentages. Scatter diagrams for the two positive deviation types are shown by Figures 17 and 18, page 32.

The comparatively poor results achieved by this method could possibly be improved by using an interval of time similar to the height change recommendation or by a less general type of study. The author does not believe that a general forecasting method based on the deviation of the 500-mb map from the normal can be formulated without the use of one of the above recommended changes. Localized methods could be developed by using the deviation method in conjunction with a possible typing of the 500-mb chart. This could involve parameters such as: wind direction over the forecast area, position of the long-wave trough in relation to the area, and other factors that can be related to a geographical area.

d. Advection of Relative Vorticity at the 500-mb Level.

Riehl, Norquest, and Sugg [6] conducted an investigation, in 1952, relating the advection of positive relative vorticity with the occurrence of precipitation. The vorticity patterns at 300 mbs were constructed using the following equation relating wind shear and streamline curvature to relative vorticity.

$$\zeta_z = KV - \partial V/\partial n$$

The above mentioned study used actual 300-mb charts, but stated that the same procedure could be used on prognostic 300-mb maps by using prognostic wind fields constructed by a new technique developed by Riehl.[1] To the knowledge of the author, no extensive statistical study has been conducted to test this method of forecasting winds. Even if this technique does prove reliable, two prognostic charts would have to be constructed, since 300-mb streamline and isotach prognostic charts would be needed to determine the vorticity. Accurate prognosis of these two fields is a difficult task.

Due to the disadvantages noted for the above mentioned technique, a different level and a different vorticity computation method were used in this study to determine the feasibility of forecasting precipitation by the advection of relative vorticity. The 500-mb level was used in this study and the finite difference expression for geostrophic relative vorticity was used to compute the vorticity patterns, namely

$$\zeta_{gz} = \frac{4g}{Fd^2}(\bar{Z} - Z),$$

which relates relative vorticity to the space mean ($\bar{Z}$) and the actual

[1] H. Riehl and C. O. Jenista, A Quantitative Method for 24-Hour Jet-Stream Prognosis, J. Meteor., 9, pp. 159-166, Feb., 1952

500-mb map (Z). The geostrophic relative vorticity represents a fairly good approximation to the actual vorticity.

The space mean chart and vorticity patterns constructed by the Aerology staff of the Naval Postgraduate School were used in this study. The space mean contours were used as streamlines for measurements of distance and direction of movement of vorticity values. The vorticity patterns on the above mentioned charts were in units of 200 feet. Only $(\bar{Z} - Z)$ had been evaluated and not the coefficient to this factor. To facilitate converting these patterns to geostrophic vorticity patterns a graph, shown in Figure 19, page 33 , was constructed.

The months of November and December of 1956, and January and February 1957 were used as sample months. The month of November was used due to the limited number of maps available in the other months. A total of 30 maps were used in this study. From these maps 35 areas where precipitation should occur were determined. An area where precipitation should occur was defined as an area where the decrease of relative vorticity along the streamlines was equal to or greater than 5×10^{-5} $\sec^{-1}$ $(10 \text{ deg lat})^{-1}$ in magnitude. This limiting gradient was determined by Riehl in his study at the 300-mb level.

The 35 examples were divided into two classes, those that occurred in the long-wave trough and those that occurred in the long-wave ridge. The long-wave inflection points were used to separate these zones. There were 22 cases in the long-wave trough class and 13 cases in the long-wave ridge class.

The long-wave trough class had a mean of 72.2 percent and a standard deviation of 15.8 percent. These values could be used to forecast 56 to 88 percent precipitation with a probability of .68 in

areas where the relative vorticity gradient decreased downwind, with the prescribed restriction, in the long-wave trough.

The long-wave ridge class had a mean of 49.9 percent with a standard deviation of 32.2 percent. The larger standard deviation in this class limits the accuracy of this method in the long-wave ridge.

The author considers this method very promising due to the encouraging results achieved in part of the above study, and believes that the results in both cases could be improved by further investigation.

4. Conclusions

a. Conclusions. Of the various methods undertaken in this study for forecasting precipitation from the 500-mb level, the author considers the advection of relative vorticity method as worthy of further study. The vorticity advection method could probably be improved to give better results, if a larger number of maps were available for the computation of precipitation areas.

b. Suggestions for Further Research. The advection of relative vorticity technique should be studied further. The minimum gradient of vorticity used in this study should be converted to a variable gradient in the opinion of the author. A large number of samples would probably indicate that this gradient should be reduced in the long-wave trough and increased in the long-wave ridge. This recommendation is made because of the presence of precipitation outside the computed areas in the long-wave trough, and the absence of precipitation in some parts of the areas in the long-wave ridge. This method would probably give better results if the vorticity fields on the space mean charts were constructed with 100 foot increments instead of 200 foot. This would assist in the determination of boundaries for the computed areas.

Another method that could be investigated for forecasting precipitation would be the typing of the 500-mb level. This is suggested by the repeated occurrence of certain contour patterns and their associated precipitation areas.

BIBLIOGRAPHY

1. H. Riehl, et al., Forecasting in Middle Latitudes, Meteor. Monographs, No. 5, pp. 47, June, 1952.

2. A. Miller, Investigation into the Relationship Between 500-mb Parameters and Synchronous Surface Weather, The Pennsylvania State University, Department of Meteorology, pp. 71, June, 1954.

3. R. G. Fleagle, Quantitative Analysis of Factors Influencing Pressure Change, J. Meteor., 5, pp. 281-292, May, 1948.

4. D. E. Martin and H. F. Hawkins, Jr., The Relationship of Temperature and Precipitation over the United States to the Circulation Aloft, Weatherwise, 1-5, pp. 113-116, October, 1950.

5. J. Namias, et al., Normal Weather Charts for the Northern Hemisphere, Tech. Paper No. 21, U. S. Dept. of Comm., Wea. Bur., pp. 43-54, October, 1952.

6. H. Riehl, K. S. Norquest and A. L. Sugg, A Quantitative Method for the Prediction of Rainfall Patterns, J. Meteor., 9, pp. 291-298, October, 1952.

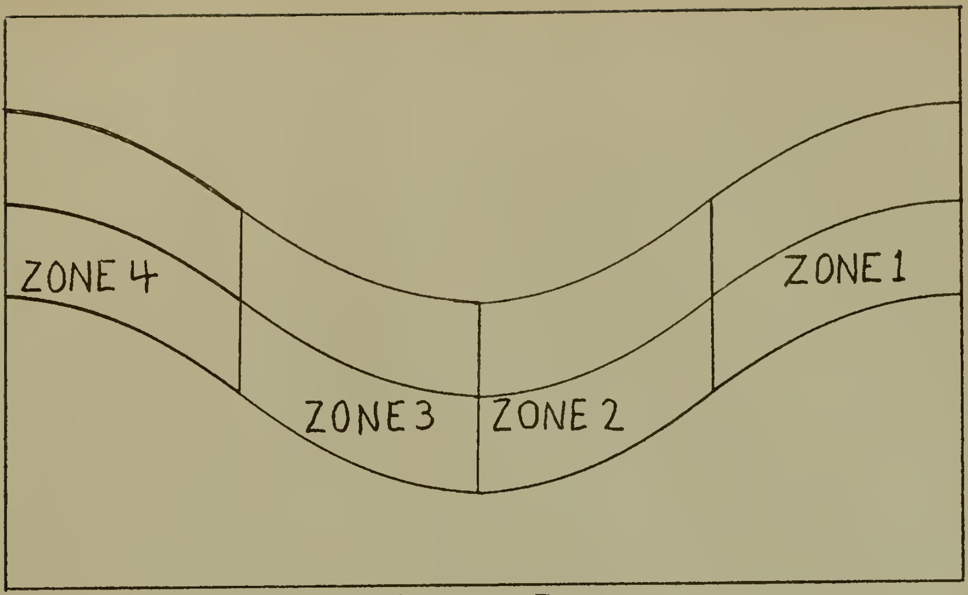

Figure 1 Wave Zones

SHORT WAVE ZONE	POSITION IN THE LONG WAVE 1	2	3	4
1	43.1	47.8	34.7	36.1
2	41.5	40.3	52.8	45.0
3	18.0	16.8	8.1	16.3
4	5.9	4.7	4.4	3.2

Table 1 Means of the Percentages of Precipitation for the Short Wave Zones

SHORT WAVE ZONE	POSITION IN THE LONG WAVE 1	2	3	4
1	22.2	21.3	14.4	15.7
2	24.1	24.9	24.9	28.2
3	21.4	19.9	10.6	18.0
4	13.3	8.5	7.1	8.9

Table 2 Standard Deviations of the Percentages of Precipitation for the Short Wave Zones

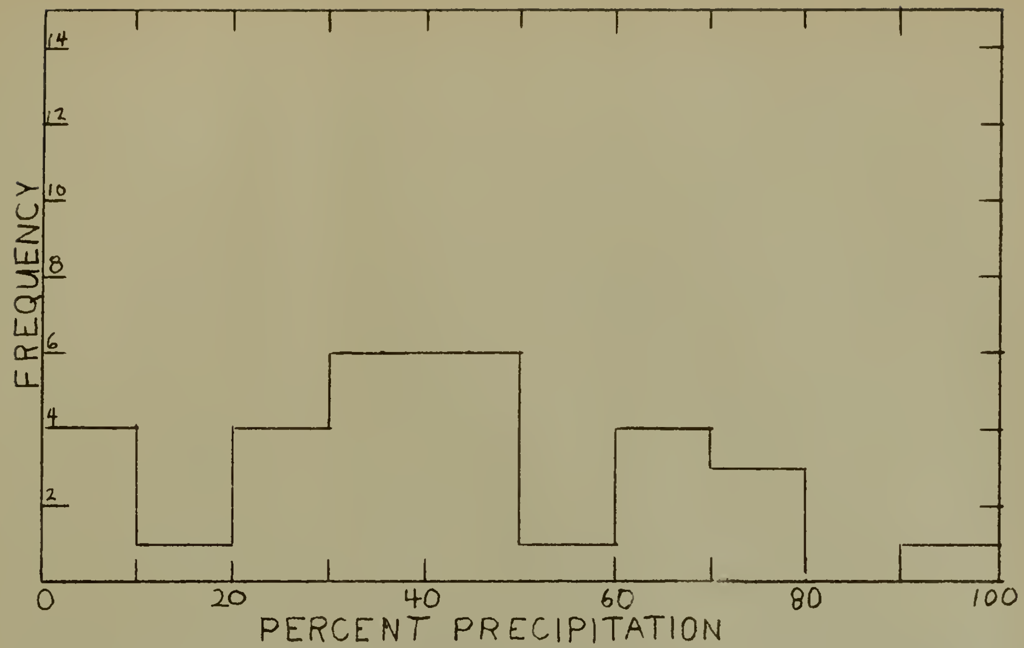

Figure 2 Frequency Distribution Graph of the Percentage of Precipitation for Zone One of the Short Wave in Zone One of the Long Wave

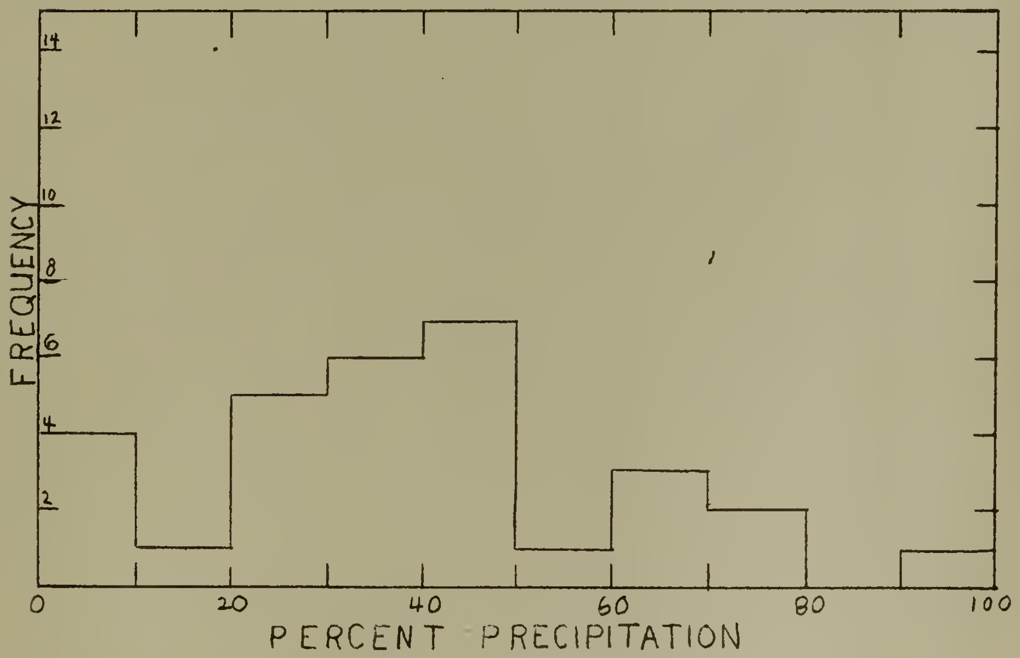

Figure 3 Frequency Distribution Graph of the Percentage of Precipitation for Zone Two of the Short Wave in Zone One of the Long Wave

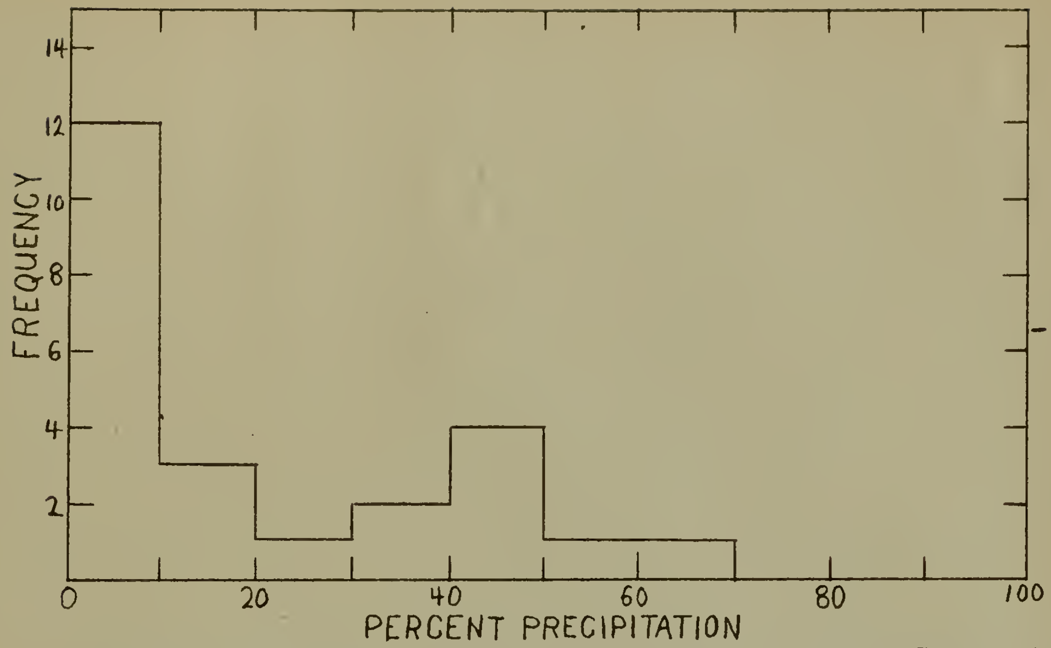

Figure 4 Frequency Distribution Graph of the Percentage of Precipitation for Zone Three of the Short Wave in Zone One of the Long Wave

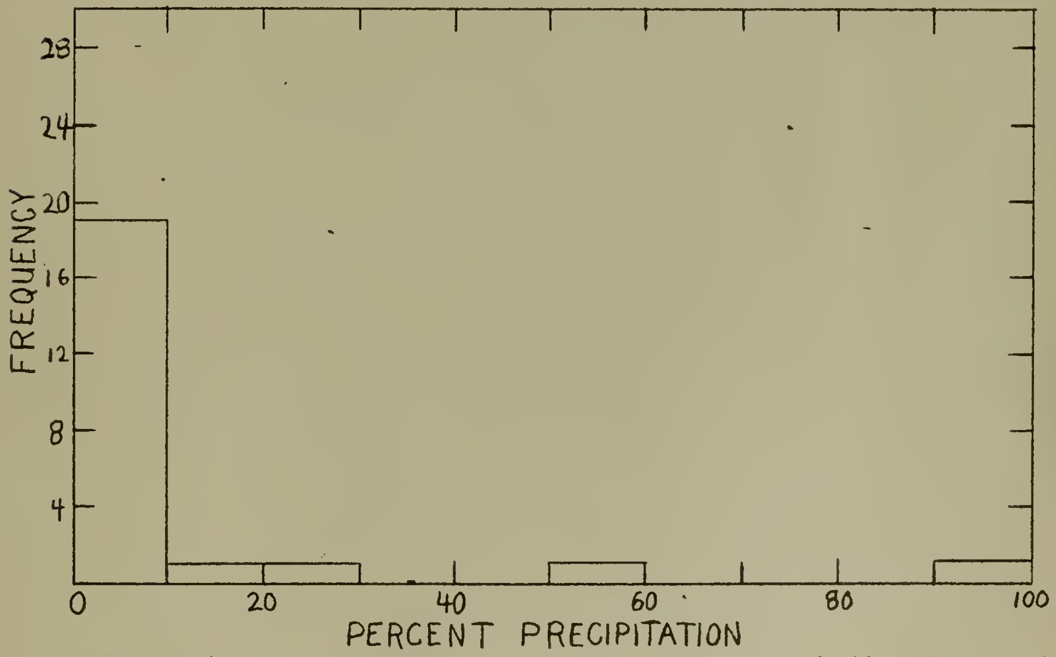

Figure 5 Frequency Distribution Graph of the Percentage of Precipitation for Zone Four of the Short Wave in Zone One of the Long Wave

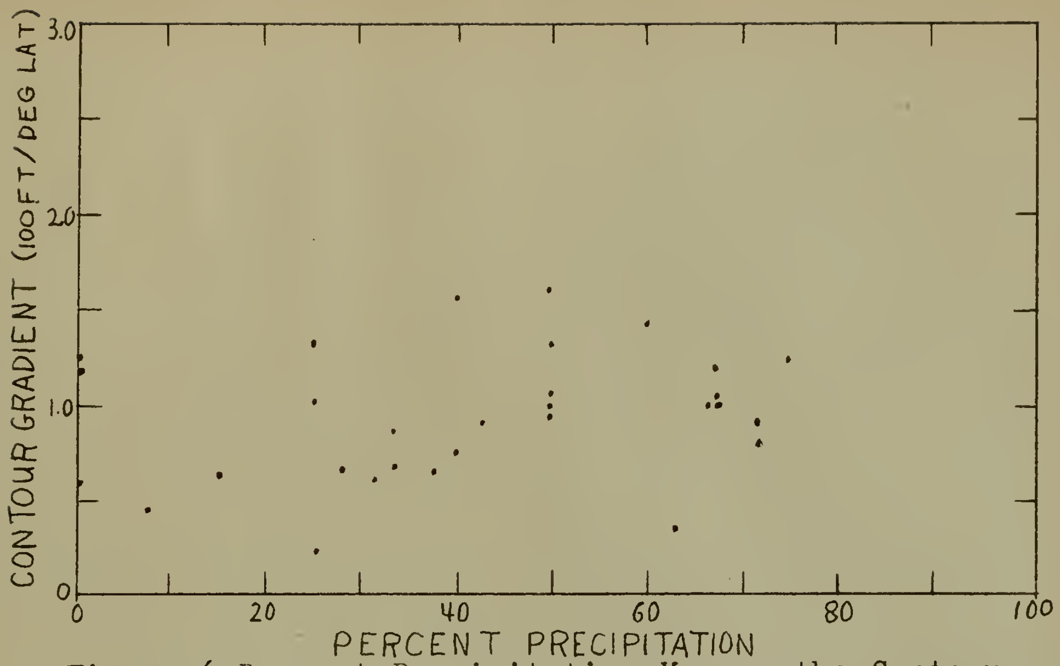

Figure 6 Percent Precipitation Versus the Contour Gradient for Zone One of the Short Wave in Zone One of the Long Wave

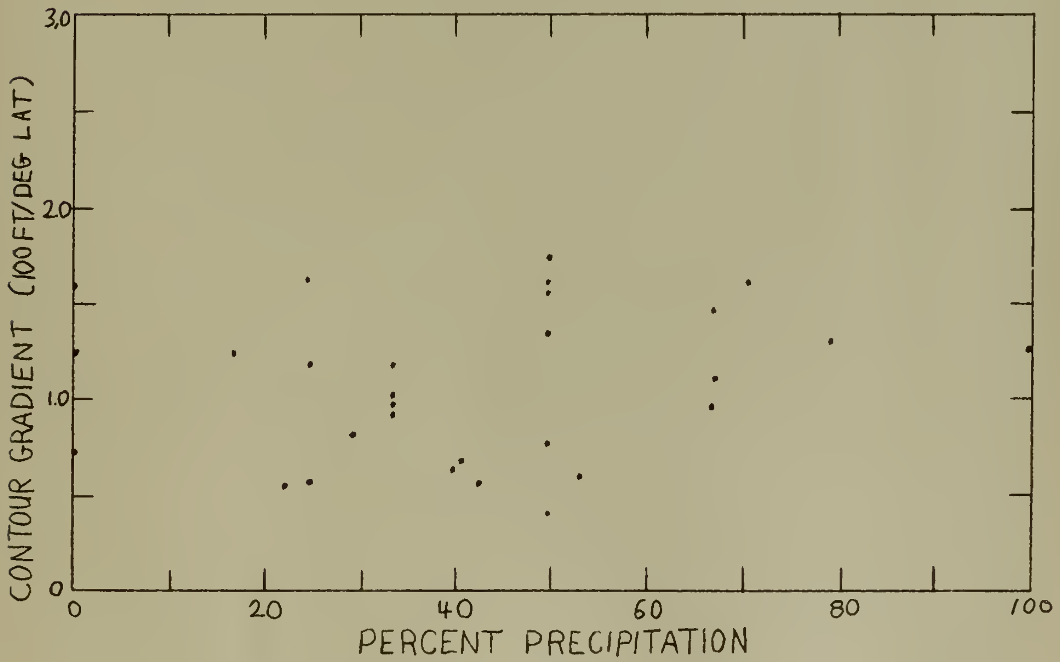

Figure 7 Percent Precipitation Versus the Contour Gradient for Zone Two of the Short Wave in Zone One of the Long Wave

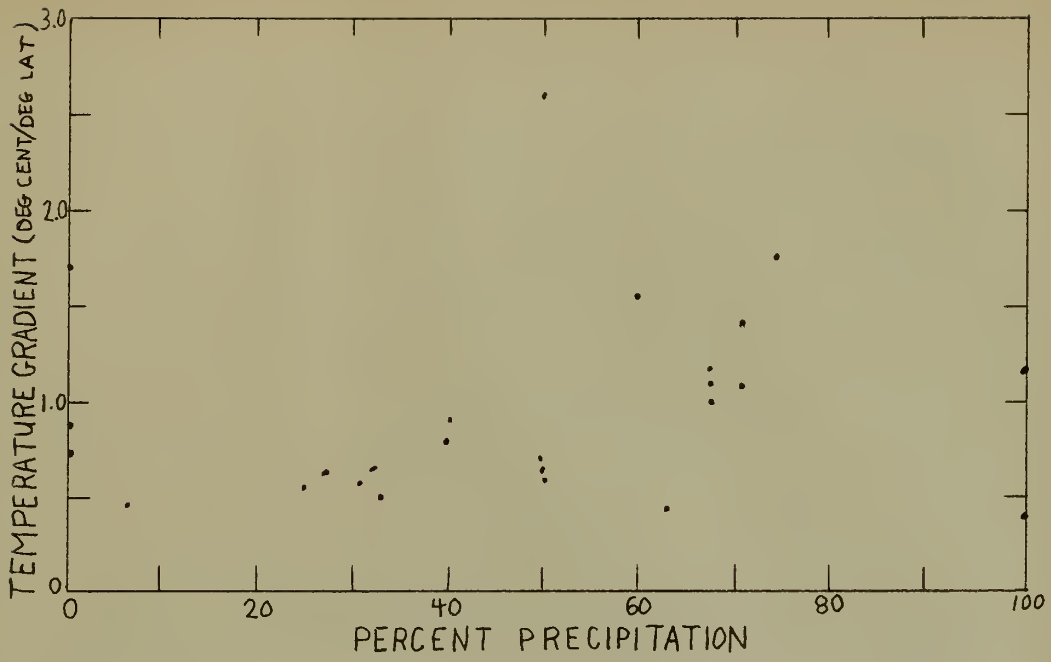

Figure 8 Percent Precipitation Versus the Temperature Gradient for Zone One of the Short Wave in Zone One of the Long Wave

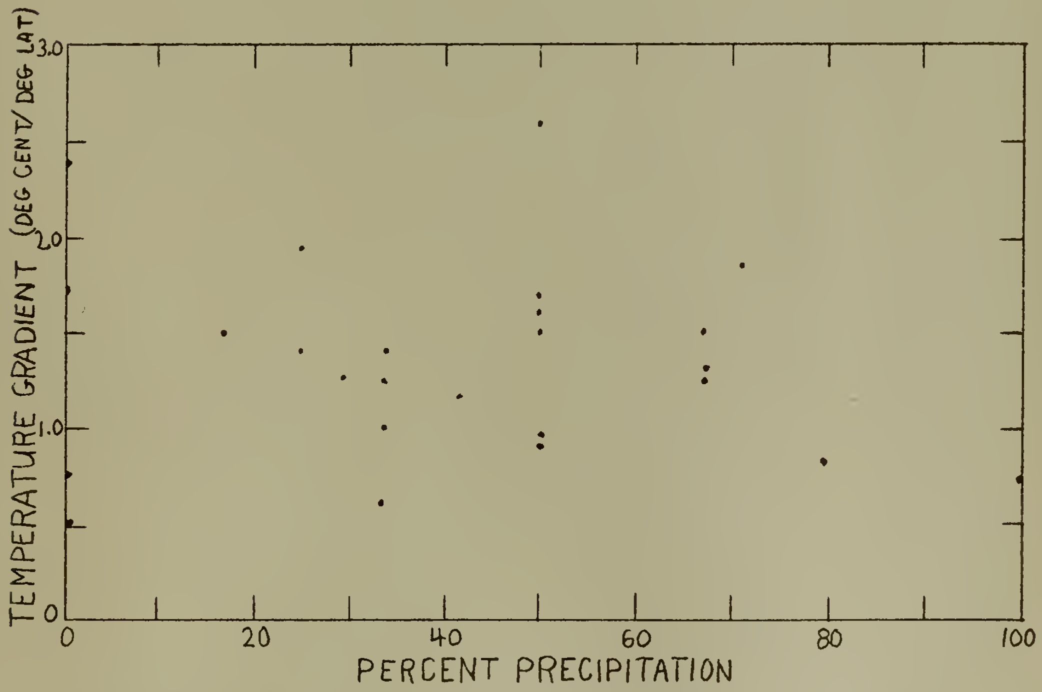

Figure 9 Percent Precipitation Versus the Temperature Gradient for Zone Two of the Short Wave in Zone One of the Long Wave

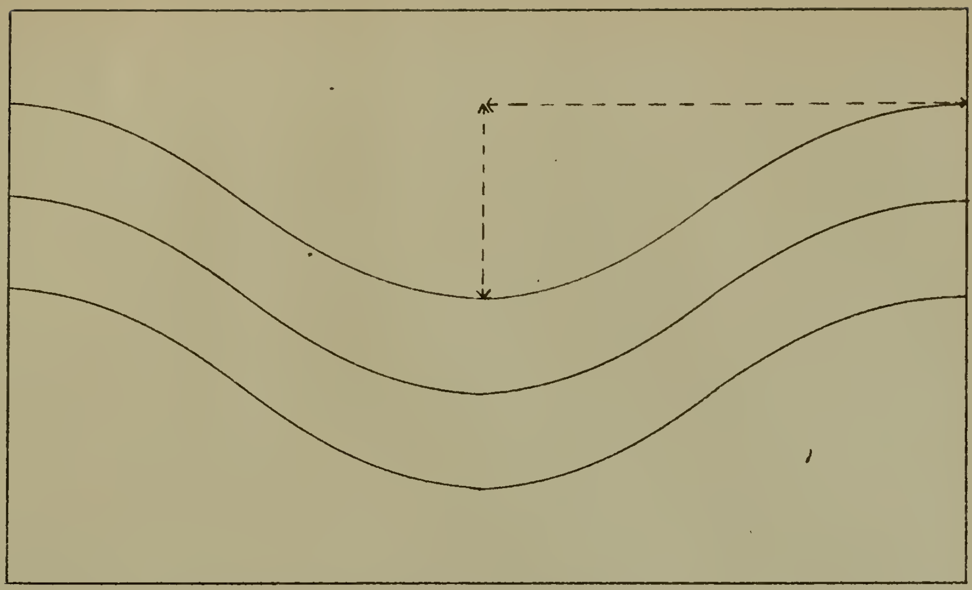

Figure 10 Steepness Factor Measurements for a Long Wave Pattern

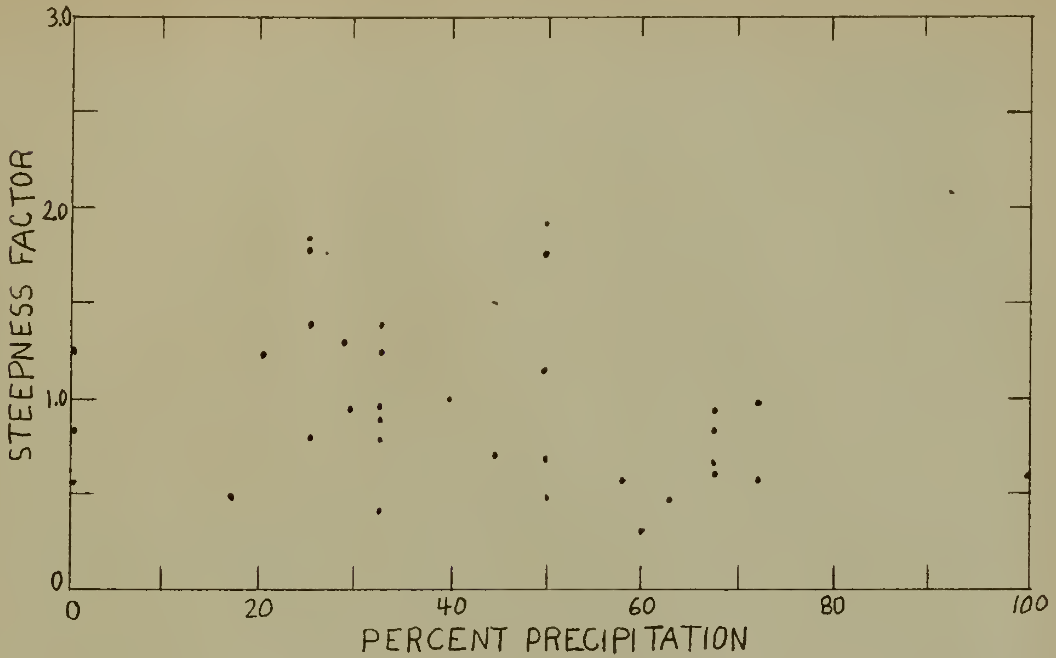

Figure 11 Percent Precipitation Versus the Steepness Factor for Zone One of the Short Wave in Zone One of the Long Wave

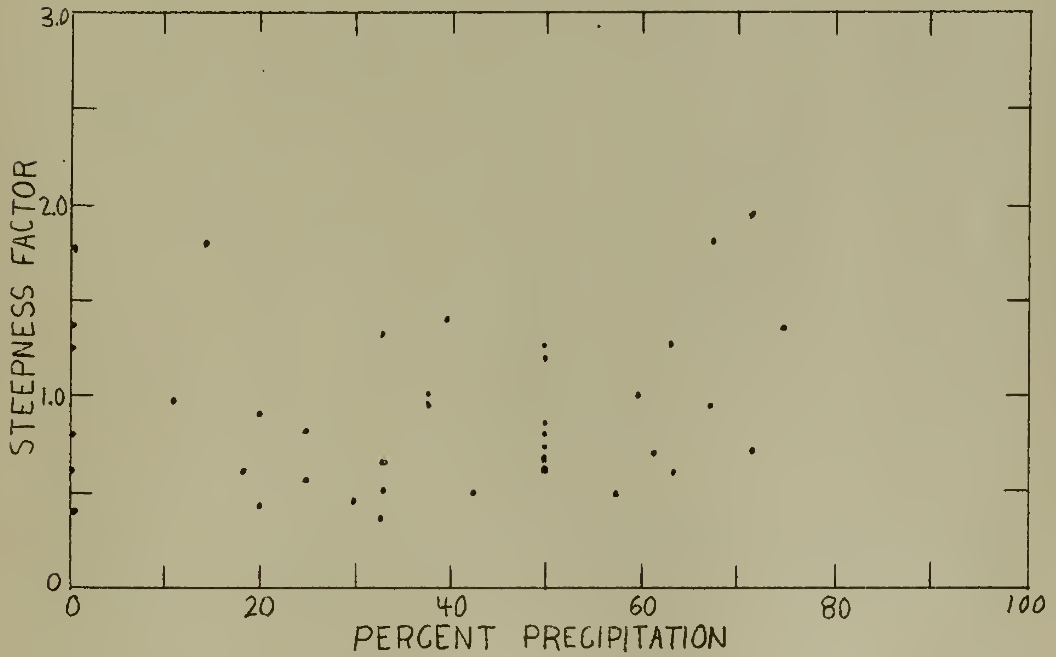

Figure 12 Percent Precipitation Versus the Steepness Factor for Zone Two of the Short Wave in Zone One of the Long Wave

WIND AREAS EAST OF 100° WEST LONGITUDE	WIND DIRECTION	SAMPLE SIZE	SAMPLE MEAN	SAMPLE STANDARD DEVIATION
	S	21	72.1	20.0
	SW	26	46.1	25.7
	N	20	20.3	23.9
	NW	22	16.2	18.1
	W	28	11.6	19.2

Table 3 Means and Standard Deviations of the Percentages of Precipitation for the Wind Direction Areas Over the Eastern United States

WIND AREAS WEST OF 100° WEST LONGITUDE	WIND DIRECTION	SAMPLE SIZE	SAMPLE MEAN	SAMPLE STANDARD DEVIATION
	S	23	49.3	33.2
	SW	23	26.7	26.5
	NW	22	14.7	19.7
	W	25	9.5	14.5
	N	20	7.0	19.5

Table 4 Means and Standard Deviations of the Percentages of Precipitation for the Wind Direction Areas Over the Western United States

MAXIMUN FALL VALUE (FEET)	SAMPLE SIZE	SAMPLE MEAN	SAMPLE STANDAND DEVIATION
-800	5	55.4	8.2
-600	15	53.0	11.1
-400	16	46.3	10.1
-200	14	38.0	19.5

Table 5 Means and Standard Deviations of the Percentages of Precipitation for the Height Fall Classes

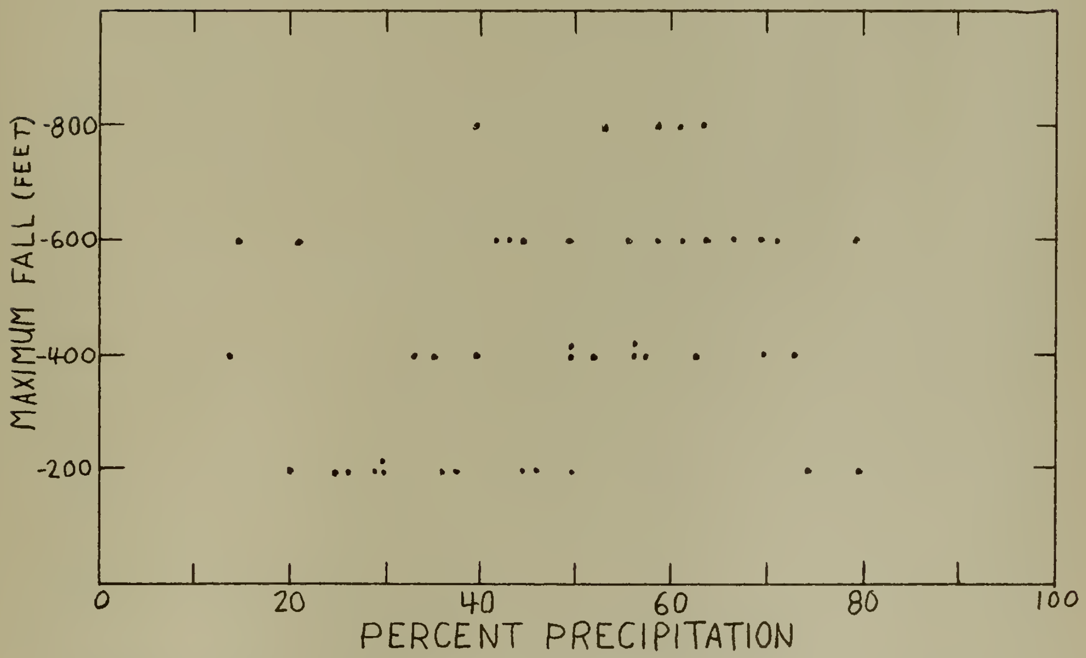

Figure 13 Percent Precipitation Versus Central Height Fall Value

MAXIMUM RISE VALUE (FEET)	SAMPLE SIZE	SAMPLE MEAN	SAMPLE STANDARD DEVIATION
600	16	9.0	12.2
400	19	5.5	10.4
200	15	5.0	9.0

Table 6 Means and Standard Deviations of the Percentages of Precipitation for the Height Rise Classes

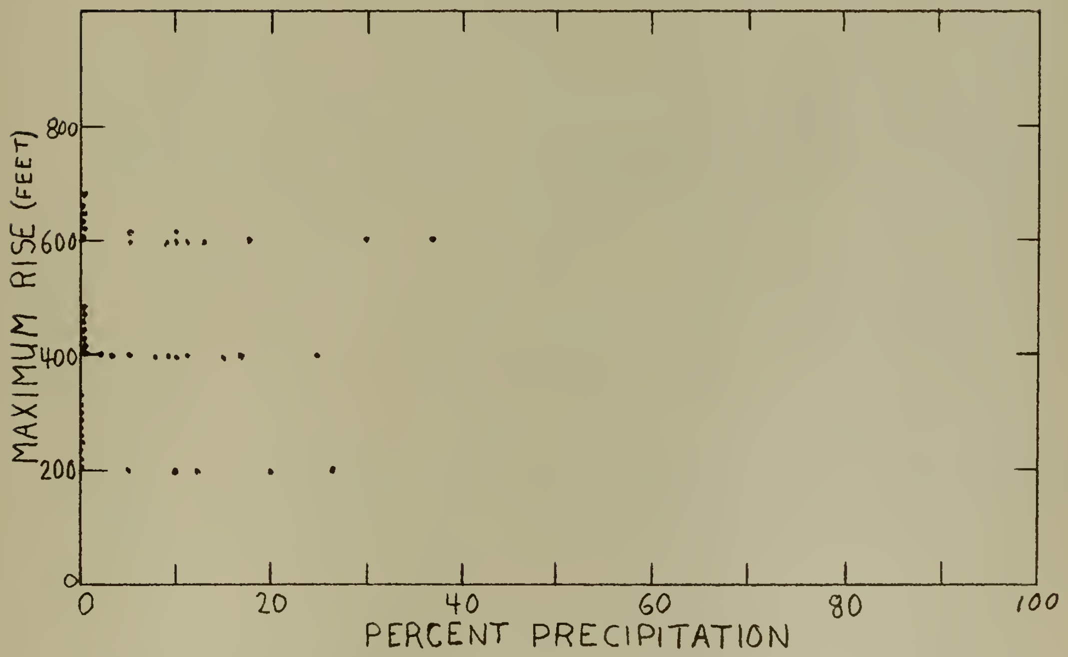

Figure 14 Percent Precipitation Versus Central Height Rise Value

LARGEST NEGATIVE DEVIATION	NO SHORT WAVE IN AREA			SHORT WAVE IN AREA		
	SAMPLE SIZE	MEAN	STANDARD DEVIATION	SAMPLE SIZE	MEAN	STANDARD DEVIATION
-200	9	23.3	15.9	7	57.8	22.8
-400	10	28.6	19.4	18	54.3	19.7
-600	14	28.4	9.2	16	61.5	10.1
-800	4	34.2	6.5	5	69.8	3.0

Table 7 Means and Standard Deviations of the Percentages of Precipitation for the Negative Deviation Classes

LARGEST POSITIVE DEVIATION	NO SHORT WAVE IN AREA			SHORT WAVE IN AREA		
	SAMPLE SIZE	MEAN	STANDARD DEVIATION	SAMPLE SIZE	MEAN	STADARD DEVIATION
200	13	3.1	6.1	6	21.0	9.3
400	24	5.3	6.3	11	20.9	16.4
600	12	4.9	4.9	4	18.7	9.4

Table 8 Means and Standard Deviations of the Percentages of Precipitation for the Positive Deviation Classes

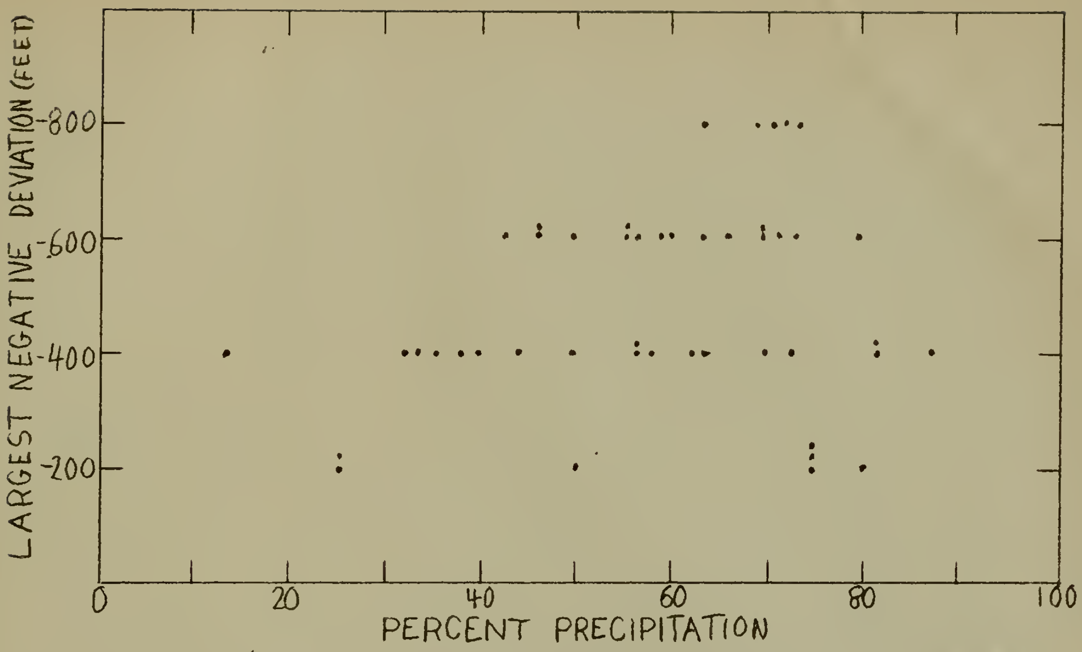

Figure 15 Percent Precipitation Versus the Maximum Negative Deviation from the Normal for Cases With Short Waves

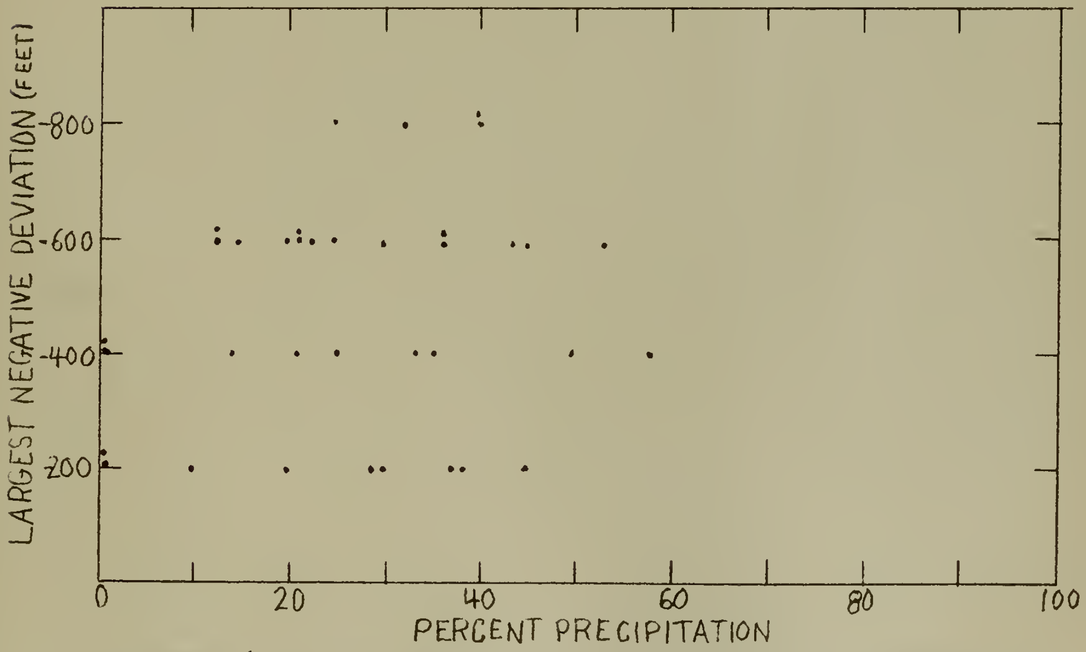

Figure 16 Percent Precipitation Versus the Maximum Negative Deviation from the Normal for Cases Without Short Waves

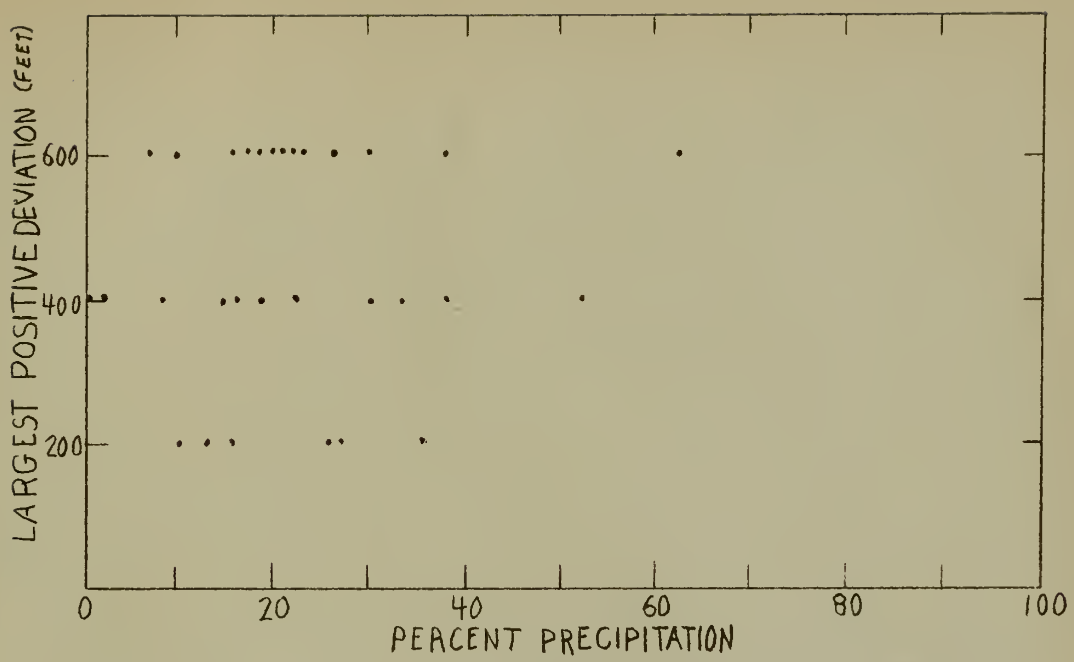

Figure 17 Percent Precipitation Versus the Maximum Positive Deviation from the Normal for Cases With Short Waves

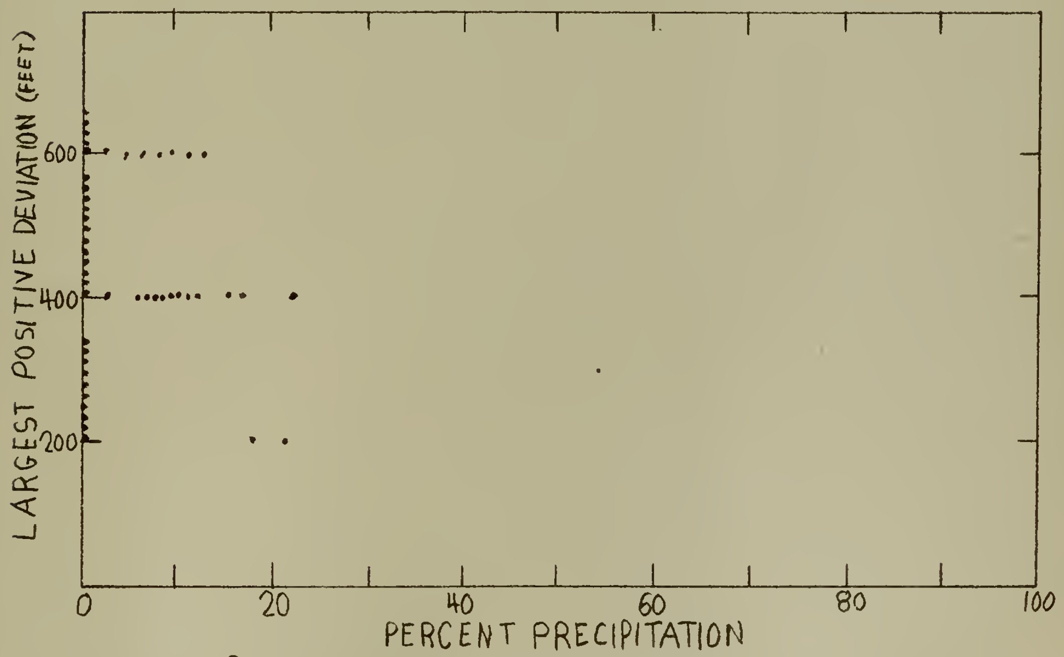

Figure 18 Percent Precipitation Versus the Maximum Positive Deviation from the Normal for Cases Without Short Waves

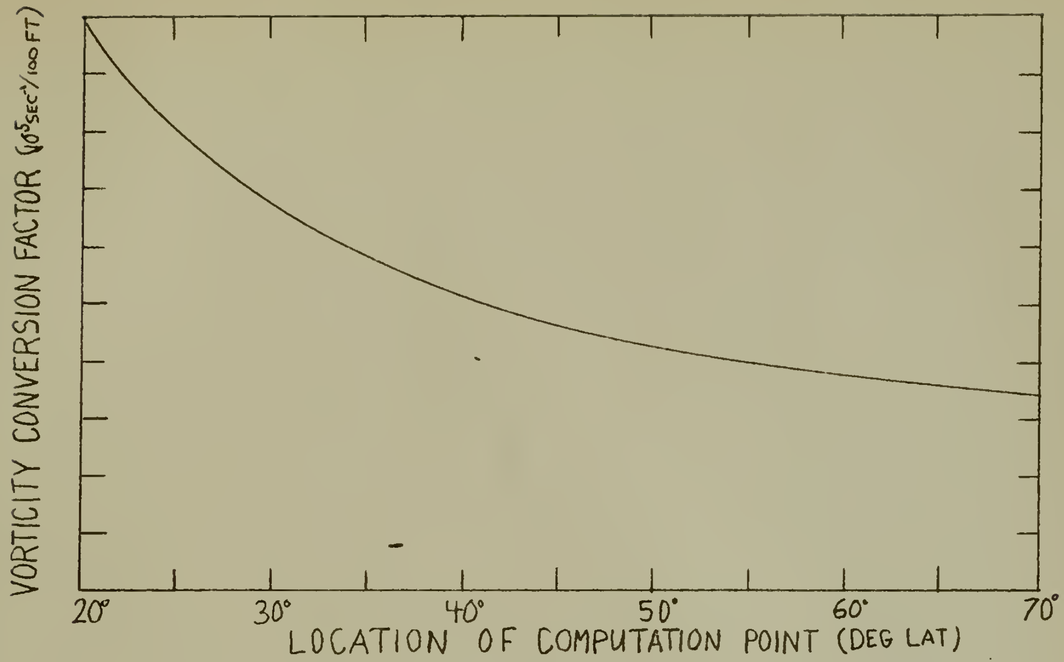

Figure 19 Conversion Graph for Geostrophic Vorticity